Performance Simulation and Cost Assessment of Oxy-Combustion Process for CO_2 Capture from Coal-Fired Power Plants

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ABSTRACT

In order to mitigate green house gas emissions, CO_2 from large sources such as coal-fired power plants should be economically captured and sequestered. This paper describes the performance modeling and cost assessment of processes designed to capture and compress CO_2 from sub-critical pulverized coal fired power plants (PC) and Integrated Gasification Combined Cycle (IGCC) units. Plant capacity of 533 MW_e gross power output firing western PRB coal was considered. Oxy-Combustion (PC-OC) and amine scrubbing technologies (PC-MEA) are considered as technology options to capture CO_2 from PC plants and Selexol process (IGCC-S) to capture CO_2 from IGCC plant. Detailed results of the mass and energy balance were obtained from steady state simulations. Cost models were developed to estimate the capital, operating, electricity and the CO_2 avoidance costs for each technology.

The process simulations showed that, with sub-critical steam cycle, the PC-OC and PC-MEA processes with CO_2 compression to 80 bars (1160 psi) decreases the net power output available by 28% and 30% respectively compared to PC plant with no capture. The economic analysis showed that the cost of electricity for the PC-OC plant increased by about 60%, PC-MEA plant by 79% and IGCC-S plant by 43%, compared to the PC plant without CO_2 capture. The CO_2 avoidance cost for a new sub-critical PC-OC plant was \$36/tonne, compared to \$52/tonne for PC-MEA plant and \$26/tonne for IGCC-S plant. For new or retrofit PC plant applications, PC-OC is more economical than PC-MEA. IGCC with Selexol is economically favorable for new coal power plants compared to a sub-critical PC plant. Economics of the PC-OC process can be further improved by considering (ultra) supercritical power plants. The detailed performance and economics results are presented in the paper along with pilot scale experimental results of the PC-OC process.

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INTRODUCTION

As large amounts of anthropogenic greenhouse gases are being emitted into the atmosphere, global warming has become one of the most important environmental issues today. Fossil fuel combustion is a major contributor of increased Greenhouse Gas (GHG) emissions. About 1/3rd of carbon emissions in the United States come from power plants, 1/3rd from transportation and the remaining 1/3rd from industrial, commercial and residential sources. As fossil fuels continue to be the dominant fuel source and electricity generation is expected to grow, reducing carbon emissions by capturing and sequestering CO_2 from energy industries is imperative.

GHG emissions can be controlled by increasing energy efficiency, switching to less carbon-intensive energy, and carbon sequestration. The first two options are not believed to be sufficient enough to achieve the GHG reduction targets. Inexpensive large-scale capture and sequestration methods are necessary to make such goals achievable. IEA research also suggested that carbon sequestration could play an important role in the deep reduction of CO_2 emissions in the first part of the 21st century [1].

The US generates about 25% of the worldwide anthropogenic CO_2 emissions [2]. The coal-fired power plants are the most significant contributors among various CO_2 emission sources. Currently, coal-fired utilities consume more than 90% of the coal used in the US [3], and are responsible for about 73% of US CO_2 emissions [4]. There is clearly a compelling need to develop new and retrofit technologies to capture and sequestrate the CO_2 emissions from coal fired power plants.

CO_2 capture cost represents around 75% of the total capture, transportation and sequestration costs [5]. The flue gas exiting a conventional air/coal power plant contains only 10% to 15% CO_2 by volume. The balance is mostly made of nitrogen (N_2). Existing capture technologies to recover CO_2 from combustion exhaust, also known as post-combustion technologies - like amine scrubbing - are expensive for CO_2 emission reduction applications. In order to effectively capture the CO_2 from combustion exhaust, one option is separating N_2 from O_2 in the air prior to the combustion. A cost-effective technology based on this principle termed as ‘Oxy-Combustion (OC)’ is presented in the paper along with detailed economical assessment and its comparison to the amine scrubbing (Monoethanolamine or MEA) technology. Experimental results obtained from pilot-scale pulverized coal fired boiler are also presented. Both retrofit and new plant cases are conceived.

Along with Oxy-combustion and MEA options for CO_2 capture from PC plants, the cost and performances of the new sub-critical PC boiler considered are also compared with Integrated Gasification Combined Cycle (IGCC) plant. IGCC is a clean power production choice; however IGCC is very capital-intensive. Oxy-combustion of coal, on the other hand, offers a cost-effective, technically viable retrofit option for existing coal boilers to achieve similar environmental benefits. PC combustion modification by OC process is a transition technology because it offers (1) significant environmental benefits and (2) the opportunity to learn and develop carbon capture and sequestration technologies with simpler operation and affordable capital costs.

OBJECTIVES

In partnership with the U.S. Department of Energy's National Energy Technology Laboratory, Air Liquide has teamed with The Babcock & Wilcox Company (B&W) and Illinois States Geological Survey (ISGS) to develop and optimize the oxy-combustion of coal process. This efficient and cost-effective approach will provide new plants and existing coal-fired fleet with improved environmental performances. The main objectives of this project are as follows:

(1) Perform an economical feasibility study, comparing combustion modifications via oxy-combustion approach with alternate technologies such as MEA,
(2) Demonstrate the feasibility and measure the performances of the oxycombustion technology with recycled flue gas on a coal-fired pilot-scale boiler.

DESCRIPTION OF THE OXY-COMBUSTION PROCESS

In oxy-combustion process, nitrogen in the air is separated prior to the combustion yielding the flue gas that is mainly composed of sequestration ready CO_2, along with easily condensable water. As combustion with pure oxygen yields very high temperatures, incoming combustion O_2 is diluted with recycled flue gases. Desired temperature and flow profiles inside the boiler are thus maintained. This process of combusting the pulverized coal in O_2-CO_2 environment is commonly referred to as 'Oxy-Combustion with flue gas recycle' or simply 'Oxy-Combustion (PC-OC)', or 'O_2-CO_2 Combustion'. The PC-OC process is schematically illustrated in Figure 1.

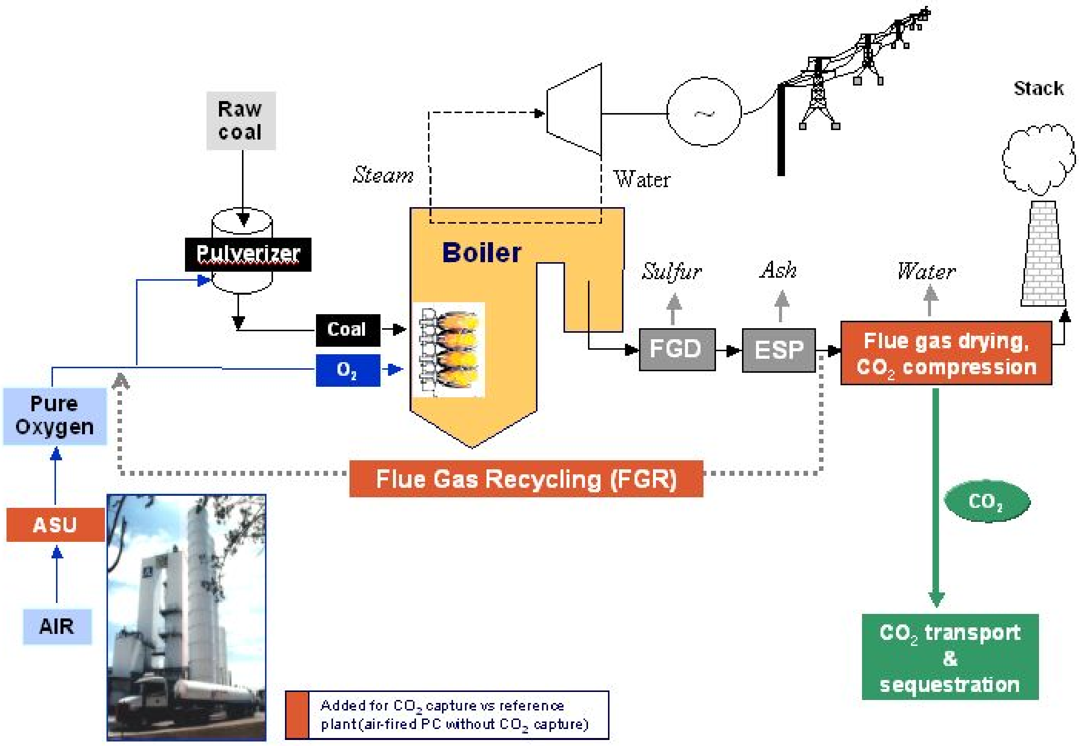

Figure 1: Oxy-combustion process for CO_2 capture from PC boiler (schematic)

In the PC-OC process investigated in this study, a flue gas desulfurization (FGD) system is located before recycling the flue gases to avoid building up corrosive sulfur compounds inside the boiler. The Electrostatic Precipitator (ESP) removes the particles (ash) to avoid damaging the recycle line. The sulfur and particle free flue gases exiting the system are CO_2-rich and four to five fold smaller in volume than from a same capacity air-fired boiler. Such drastic reduction leads to cost-effective further purification if needed, to meet the CO_2 specification for reuse (Enhance Oil Recovery-EOR, Enhanced Coal Bed Methane-ECBM) or geological sequestration options. As measured on the pilot-scale boiler, the PC-OC process reduces the NO_x emission by up to 60 to 70% versus a staged air-fired baseline. Hence, a Selective Catalytic Reduction (SCR) unit may not be necessary for NO_x control and is not considered in the study.

The PC-OC technology also offers a wide variety of alternatives. For a new power plant, the amount of FGR would be set to a minimum, enabling more compact design of some boiler equipment. For a retrofit of an existing boiler, the FGR is set so that the heat transfer characteristics of the boiler operation would remain similar to the air-fired case.

TECHNO-ECONOMIC ANALYSIS

The techno-economic study of the CO_2 capture from conventional pulverized coal boiler with MEA and O_2-CO_2 combustion was performed by the Illinois State Geological Survey (ISGS) with inputs from American Air Liquide. Two main processes are currently being investigated for CO_2 capture from PC boilers:

- The PC-OC process, that separates N_2 from O_2 prior to combustion to yield CO_2-rich flue gases (see Figure 1)
- The post-combustion process (PC-MEA), that uses amine-type sorbent to scrub the CO_2 from nitrogen rich flue gases produced via air-firing (see Figure 2)

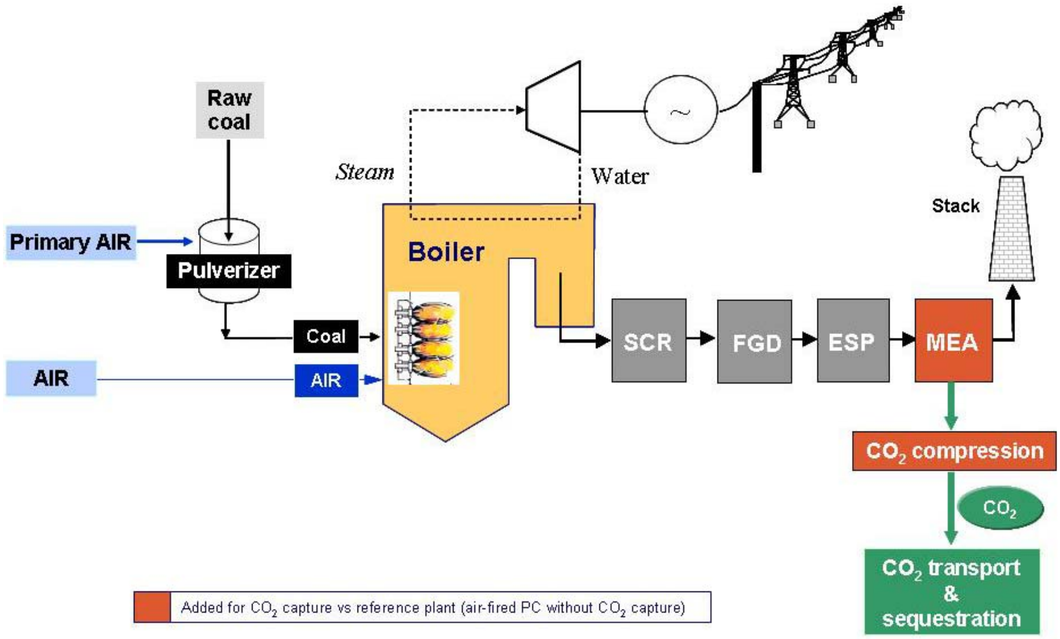

Figure 2: Conventional air-fired coal-combustion equipped with Amine scrubber for CO_2 capture (schematic).

In addition to PC plants, another power generation technology, Integrated Gasification Combined Cycle (IGCC) was also considered and the economics of this plant are compared with new PC-OC and PC-MEA plants. It is to be noted that the steam cycle assumed in the present study is <u>sub-critical</u> for PC plants and hence the comparison with latest IGCC technology is not fair. This assumption for PC plants was due to the fact that the main purpose of the techno-economics performed in this study was for retrofit applications rather than for new plants. A new PC plant with super or ultra-supercritical steam cycle would be a fair comparison with IGCC but is beyond the scope of this project. Table 1 summarizes the plants investigated in this study.

Table 1: Plants investigated in the Techno-Economic analysis and corresponding acronyms.

Acronym	Plant Description	Comments	Applications
PC-Reference	Conventional Air-fired pulverized coal boiler	No CO_2 capture. Used as a reference to calculate the increase in cost of electricity, and the cost of CO_2 avoided	-
PC-MEA	Air-fired equipped with **MEA unit for CO_2 capture**	CO_2 capture plant	**Retrofit** or New Plant
PC-OC	PC boiler fired with **oxygen-enriched flue gases for CO_2 capture**	CO_2 capture plant	**Retrofit** or New Plant
IGCC-S	IGCC equipped with a **selexol unit for CO_2 capture**	CO_2 capture plant	New Plant

Process Simulation

CHEMCAD software was used for process simulation and calculation of mass and energy balances. The process was divided into four parts, coal combustion, steam generation, flue gas cleaning and either CO_2 capture by MEA or ASU for O_2 generation as listed below. Typical design and operating conditions of these processes were obtained from literature [6, 7, 8, and 9].

(1) Combustion
- ✓ Coal and Air/O_2 feed
- ✓ Boiler combustion
- ✓ Super heater, re-heater, economizer and air pre-heater
- ✓ Flue gas recycle (FGR)

(2) Steam turbine generator
- ✓ Steam turbine (HP, IP, LP)
- ✓ HRSG
- ✓ Cooling water system
- ✓ Feed water and miscellaneous systems (FWH 1-7, Deaerator)

(3) Flue gas cleaning
- ✓ ESP for Ash
- ✓ FGD (Lime Spray Dryer/LSD) for SO_x
- ✓ SCR for NOx

(4) MEA process for CO_2 capture or ASU for O_2 generation.

One important parameter that was fixed in the techno-economic assessment for all the cases was the gross power output, which is 533 MW_e. Many of the processes listed above consume significant amount of energy/electricity (auxiliary power), especially ASU and MEA, which impacts the net output of the power plant. Hence the following definitions are defined to evaluate the efficiency of the process.

Net Power Output = Gross Power Output – Auxiliary Power Input
Net plant efficiency = Net power output/total thermal input

Cost Assessment

Capital Cost

For assessing cost of the power generation technologies, DOE classified a power plant into 14 process areas. This study also follows the same classification for evaluating the costs of different components which are obtained by scaling DOE's reference plant [6, 7]. Each process area is divided into sub-areas and many types of equipment may exist in each sub-area. Cost assessment is made at process level for the study.

Table 2: DOE's Process Areas Classification of a Power Plant

1. Coal handling	6. HRSG, ducting and Stack	12. Improvements to site
2. Coal preparation & feed	7. Steam turbine generator	13. Buildings and structures
3. Feed water &misc.	8. Cooling water system	~~14. Gas turbine generator~~
4. PC boiler & accessories	9. Ash/Spent sorbent handling system	
5. Flue gas cleaning ESP, LSD, SCR	10. Accessory electric plant	
	11. Instrumentation & control	

Gas turbine generator, which is a process area, is not considered for the study as only steam turbines are considered. Apart from the mentioned 13 process areas in Table 2, three more areas are considered which are specific to the study:

14. CO_2 separation (MEA)
15. ASU (O_2 production)
16. FGR

Operating and Maintenance Costs

Cost and expenses associated with operating and maintaining the plant include:

- ✓ Operating labor
- ✓ Administrative and support labor
- ✓ Maintenance labor and materials
- ✓ Consumables
- ✓ Fuel (Coal) cost

Operating and supportive labor costs are estimated on the basis of the number of operating jobs (OJ) required to operate the plant. The OJ data are not related to the plant size, but depend on the number of units under operation. Therefore, the representative OJ data of major plant areas in literature were used.

Annual cost of maintenance labor and materials is estimated as a percentage of the installed capital cost. The percentage varies widely, depending on the specific processing conditions and the type of design for each process area. From literature, the representative percentage was selected for each process area.
Consumables include:

- ✓ Water makeup for steam cycle and miscellaneous use
- ✓ Water treating chemicals
- ✓ Waste water treating chemicals

- ✓ L.P Steam
- ✓ Lime (for LSD)
- ✓ SCR catalyst
- ✓ Ammonia
- ✓ Amine

Based on the results from the process simulation, the mass flows of the consumables listed above are calculated. Their costs were estimated based on unit market price. As mentioned before, addition of MEA or ASU impacts the net power output of the plant. In order to take this impact into consideration, all the capital and operating costs are in \$/kW or \$/kWh based on net kW_e output. The capital costs are levelized over a period of 20 years assuming an inflation rate of 4.1%.

Cost of CO_2 Avoided

Cost of a CO_2 capture system is generally expressed in terms of either cost per tonne of CO_2 removed or cost per tonne of CO_2 avoided. For systems like MEA and ASU that are very energy intensive, the costs per tonne of CO_2 removed and avoided are very different. To take into account the reduced net power output resulting from CO_2 capture, the cost of CO_2 avoided is more relevant. This economic indicator is calculated using the following formula [10].

Cost of CO_2 avoided (\$/tonne): $\dfrac{(\$/kW_h)_{cap} - (\$/kW_h)_{ref}}{(tonCO_{2emitted}/kW_h)_{ref} - (tonCO_{2emitted}/kW_h)_{cap}}$, where:

cap = capture plant (PC-OC or PC-MEA)
ref = reference PC plant without CO_2 capture
$\$/kW_h$ = levelized COE
$tonneCO_{2emitted}/kW_h$ = metric tonne of CO_2 emitted by the plant per kW_h net generation

Key Assumptions

In summary, following are the key assumptions that are made in this study.

- ✓ Gross power output: 533 MWe
- ✓ O_2 purity: 99% for PC and 95% for IGCC
- ✓ Fuel: PRB coal
- ✓ Generation: sub-critical steam turbine for PC plants
- ✓ Life of equipment: 20 years for new and retrofit plants
- ✓ Inflation rate: 4.1%, discount rate: 9.25%
- ✓ MEA: Fluor Daniel Econamine FG process with 90% solvent efficiency
- ✓ LSD and SCR: 90% efficiency
- ✓ Capacity factor: 70%

RESULTS AND DISCUSSION

The following parameters were calculated for four different plant configurations mentioned in Table 1.

- ✓ Overall performances of the plants
- ✓ Capital costs in \$/kWe
- ✓ Operating costs in \$/kWe/Yr

- ✓ Electricity costs in mills/kWh
- ✓ CO_2 costs in terms of $/tonne of CO_2 avoided
- ✓ Sensitivity analysis of ASU and MEA capital cost and power consumptions

Overall Performances of the Plants

The overall performances of the different plant configurations for new and retrofit cases are presented in Figure 3 and Table 3.

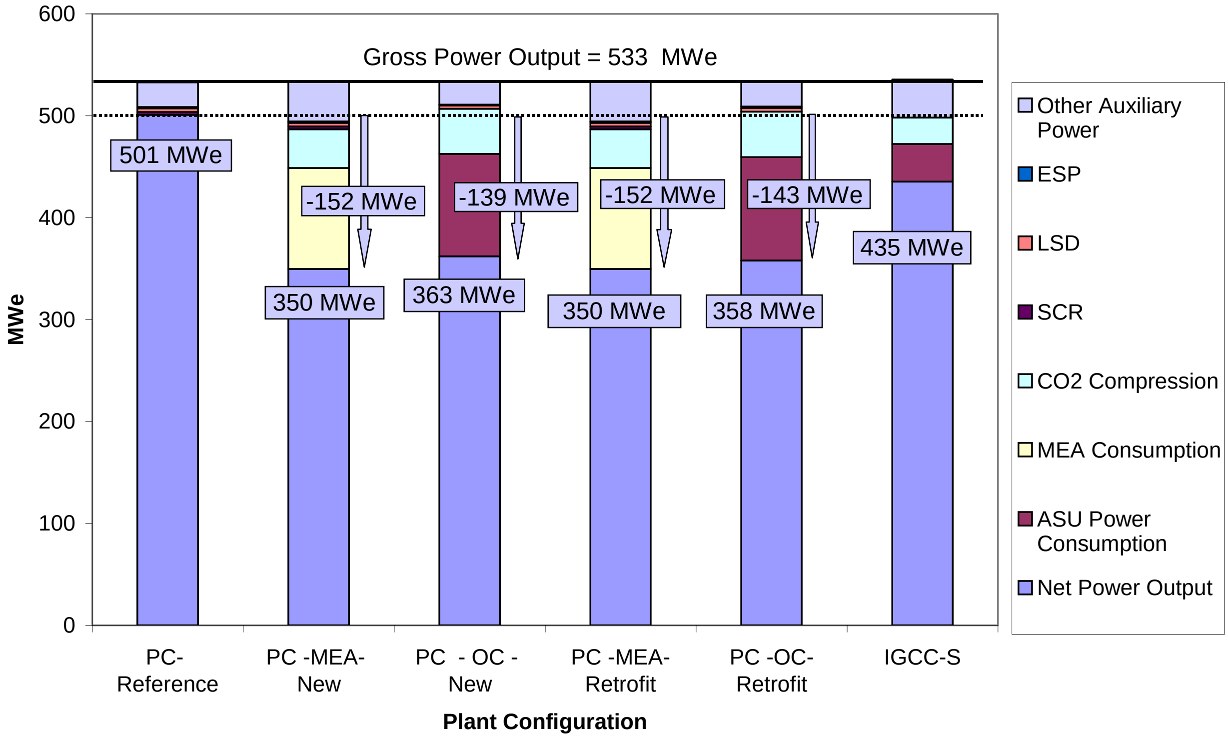

Figure 3. Overall Performances of the Plants

Table 3. Overall Performances of the Plants

	PC - Reference	PC- MEA - New	PC-OC-New	PC- MEA - Retrofit	PC-OC-Retrofit	IGCC-S
Gross Power (MW_e)			533			
Other Aux. Power (MW_e)	24.3	39.4	22.0	39.4	24.1	37.4
CO_2 compression (MW_e)	-	38.0	44.3	38.0	44.7	26.0
MEA Power (MW_e)	-	99.0	-	99.0	-	-
ASU Power (MW_e)	-	-	100.6	-	101.5	36.8
SCR (MW_e)	2.8	2.8	-	2.8	-	-
LSD (MW_e)	3.5	3.5	3.2	3.5	3.6	-
ESP (MW_e)	1.3	1.3	1.0	1.3	1.5	-
Net Power (MW_e)	**501.0**	**349.8**	**362.0**	**349.8**	**357.9**	**435.5**
Net efficiency, HHV (%)	37.0%	25.8%	27.9%	25.8%	27.3%	36.2%

It is evident from the above figure and table that PC-MEA and PC-OC processes are very energy intensive. PC-MEA process uses steam for amine regeneration and thus the net power output dropped from 501 MWe to ~350 MWe. For PC-OC process, the ASU needs electric power to produce the oxygen and consumes about 20% (100 MWe) of the net power output available from baseline plant. Due to these huge parasitic loads, the net efficiency of the plants decreased from 37% to 25.8% for PC-MEA new and retrofit plants, 27.9% for PC-OC-New and 27.3% for PC-OC-Retrofit plants. For PC plants, OC is better than MEA in terms of overall performances for new and retrofit configurations. For new plants, IGCC-S is more efficient than PC plants but it is to be noted that the PC plants here feature a sub-critical steam cycle that explains the difference in the performances. PC plants with latest supercritical or ultra supercritical steam cycle would be a fair comparison to IGCC-S. CO_2 compression is the second largest consumer of the power next to MEA and ASU consumptions.

Capital Costs

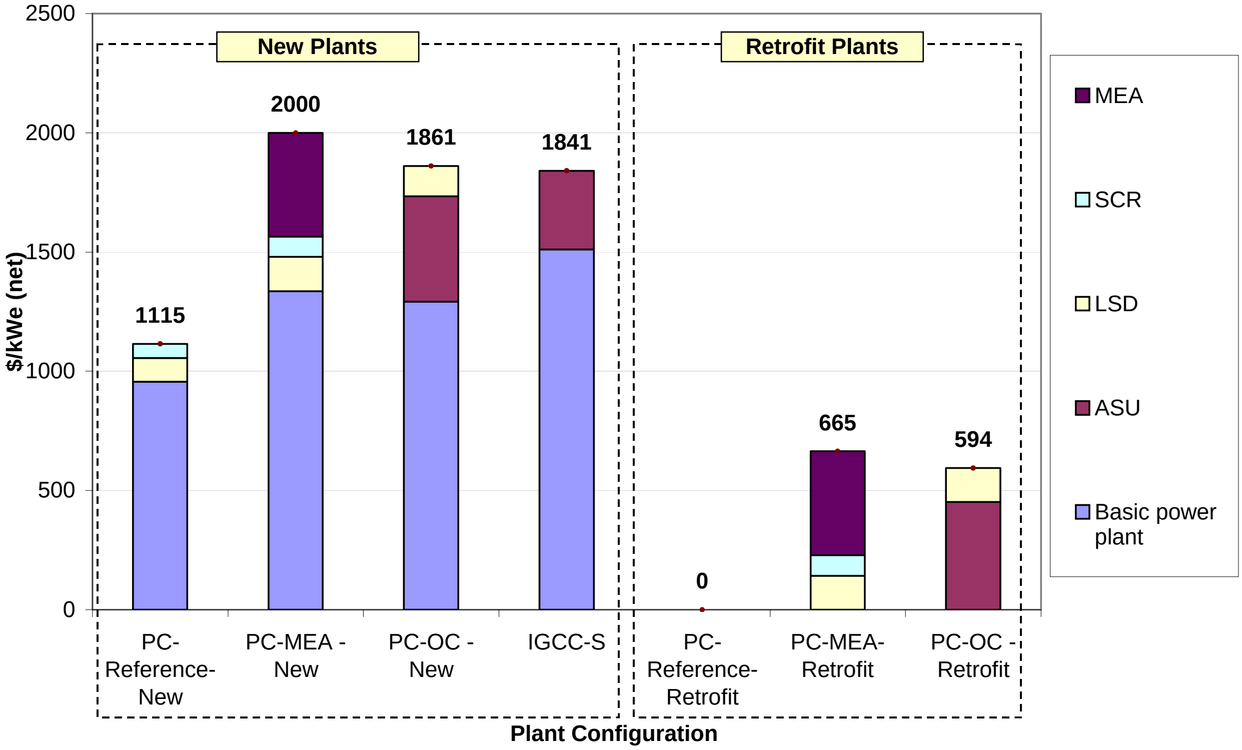

Figure 4. Capital Costs of different plant configurations

Figure 4 shows the capital requirements normalized with net kWe output for all the plant configurations considered. For new plants, the capital cost increased from $1,115 /kWe to $2,000/kWe for MEA plant and $1,861/kWe for OC plant. New OC plant requires 7% less capital than a new MEA plant. For retrofit cases, it was assumed that the basic plant cost is paid off and equipment specific to OC or MEA plants is considered along with flue gas cleaning systems (LSD for OC; SCR and LSD for MEA plant). In order to retrofit the reference PC plant considered with CO_2 capture systems, an additional capital of $665/kWe is required for MEA option and $594/kWe for OC option. The retrofit capital of OC plant is 10% lower than the MEA retrofit. The capital cost of new OC plant is almost equal to that of IGCC plant.

Operating and Maintenance (O&M) Costs

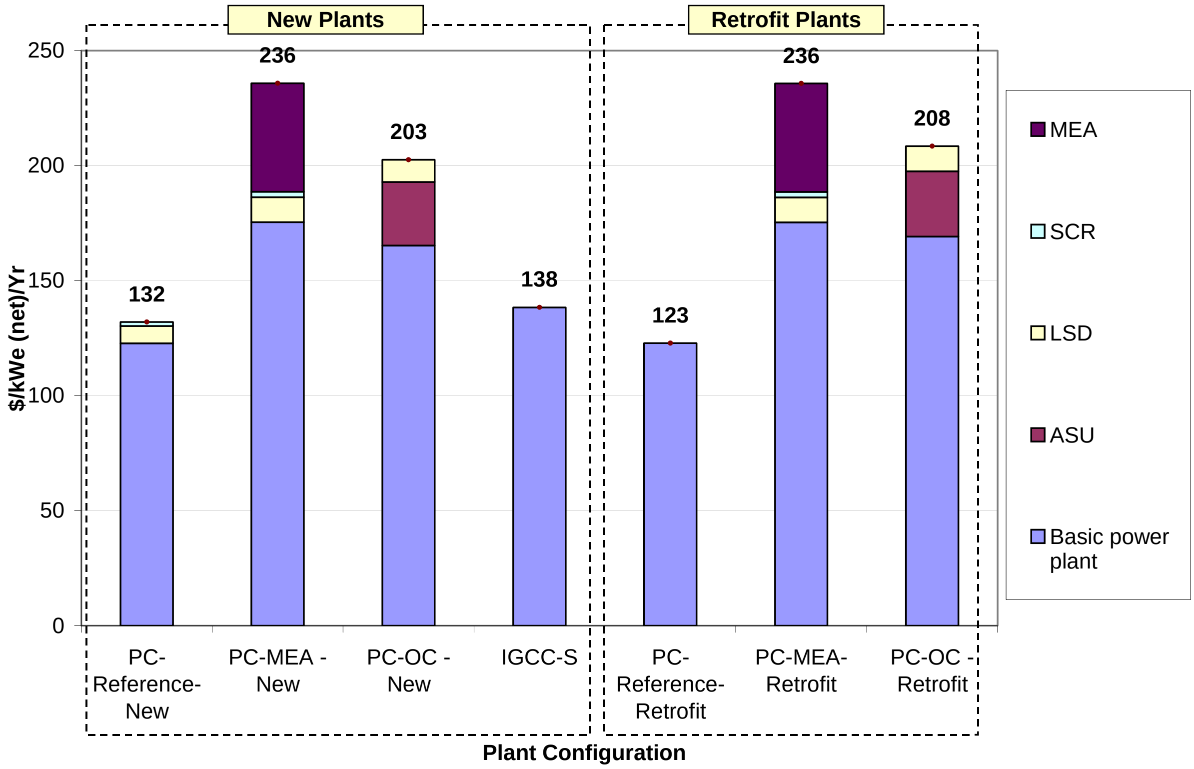

Figure 5. Operating and Maintenance costs of different plant configurations

Figure 5 illustrates the O&M costs per year of different plant configurations considered normalized with net power output. For new and retrofit PC plants, the overall O&M cost of OC plant is ~14% lower than that of new MEA plant. The O&M cost associated with ASU is more than 40% lower compared to MEA system for both new and retrofit cases. The O&M costs associated with the IGCC plant is much lower (30% to 40%) than that of PC plants because of the fact that the efficiency of the IGCC plant is much higher than the sub-critical PC plant considered. The industry experience showed that when utilities purchase new supercritical PC boilers to increase cycle efficiency, the fuel cost is reduced because of lower heat rate requirements. With PC-OC process, (ultra) supercritical boilers also require less oxygen per MWe generated. Hence, the O&M costs of PC boilers could be much lower than showed here.

CO_2 Avoidance and Electricity Costs

Figure 6 shows the CO_2 avoidance costs (in \$/tonne CO_2) and increase in cost of electricity (in mills/kWhr) for all the plant configurations considered. It is evident from the Figure 6 that OC plants have lower CO_2 avoidance costs for both new and retrofit PC applications. The CO_2 avoidance cost of a new PC-OC plant (\$36/tonne CO_2) is 30% lower than that of corresponding MEA (\$52/tonne CO_2) plant. For retrofit applications, the CO_2 avoidance costs of PC-OC plant (\$48/tonne CO_2) is 25% lower than that of MEA plant (\$64/tonne CO_2) and are higher for both plants compared to the new plant configurations. This is due to the fact that the baseline plant considered for retrofit application did not have either SCR or LSD and they are added in the CO_2 capture plants.

Addition of CO_2 capture units increases the cost of electricity significantly. For new OC plants the electricity cost increased by 31 mills/kWh and for new MEA plants by 40 mills/kWh (compared to basic PC cost of 50 mills/kWh). However, the increase for OC plants is lower than that of corresponding MEA plant. The increase in electricity cost for retrofit applications is higher than new plant cases due to the same reason that the baseline plant did not assume SCR and LSD units.

Under current technical assumptions for PC plants, IGCC plant equipped with Selexol for CO_2 capture has lowest CO_2 avoidance cost (\$27/tonne CO_2) and electricity cost. In order to better compare IGCC with new PC plants, as mentioned before, PC plants should feature latest supercritical or ultra-supercritical steam cycles.

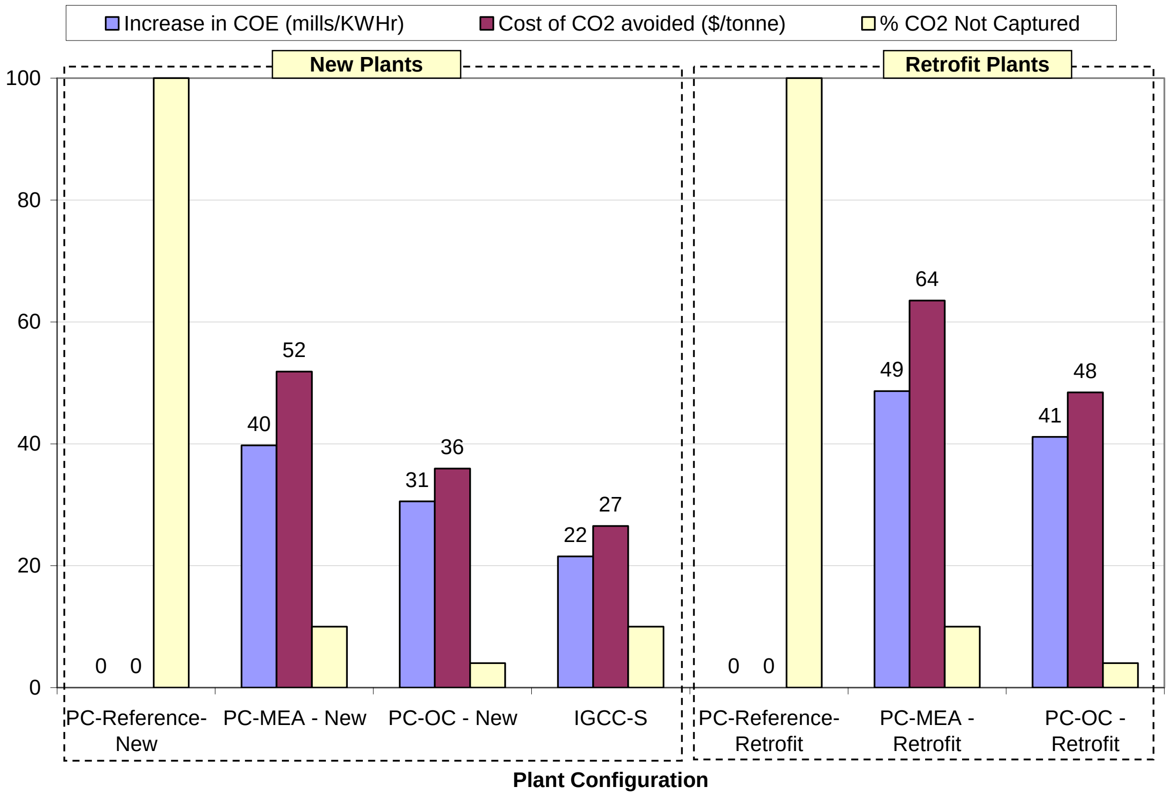

Figure 6. CO_2 avoidance and electricity costs

Sensitivity Analysis

In order to better understand the impact of ASU and MEA capital and operating costs on the CO_2 avoided costs, a sensitivity analysis was performed. As illustrated in Figure 7, lowering either the capital or operating costs of ASU or MEA units lower the CO_2 avoided costs but, the impact of ASU/MEA power consumptions is greater than the impact of capital costs. Decreasing the ASU or MEA power consumption by 50% lowers the CO_2 avoided costs by \$12/tonne for PC-OC plant and by \$16/tonne for PC-MEA plant. Lowering the capital costs of ASU and MEA by 50% decreases the CO_2 avoided costs by only \$6/tonne for PC-OC plant and \$9/tonne for PC-MEA plant. Improving both capital costs and operating costs of CO_2 capture plants can lower the CO_2 avoided cots significantly.

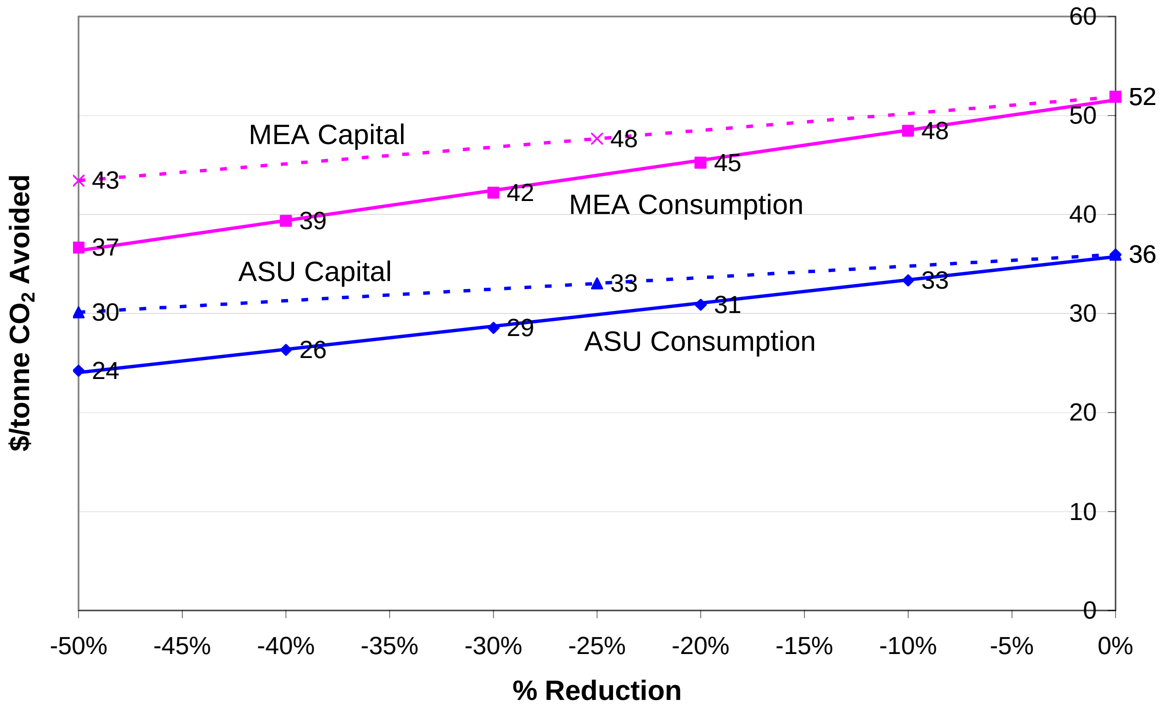

Figure 7. Sensitivity of ASU and MEA capital and operating costs

Experimental Results: Oxy-Combustion demonstration on a pilot-scale boiler

The feasibility of switching from air to O_2-enriched flue gas (oxy-combustion) operation has been successfully demonstrated. The demonstration part of the project was carried out in collaboration with B&W. The purpose of the demonstration was to prove the feasibility of the PC-OC process and compare the process performances to air-blown combustion.

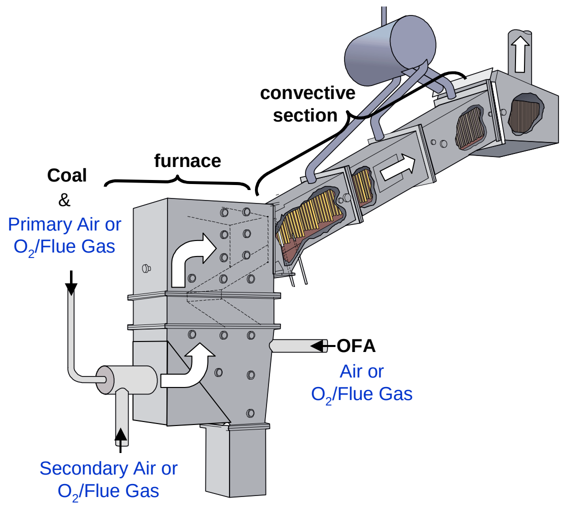

Figure 8: 1.5MW$_{th}$ Pilot boiler Simulator

The pilot boiler, referred to as a Small Boiler Simulator (SBS), located at B&W Research Center, is depicted in Figure 8. This 1.5MW$_{th}$ (5 million Btu/hr) pilot-scale boiler accurately replicates the combustion and convection pass characteristics of a full-size utility boiler. The Primary, Secondary and Overfire Air (PA, SA, OFA) of a conventional air-blown boiler were replaced by oxygen-enriched flue gas (O_2/CO_2).

Tests were performed with a low-sulfur sub-bituminous coal. The detailed experimental results are reported in an earlier paper [11]. The key results are described in the following sections

NO$_x$ emissions

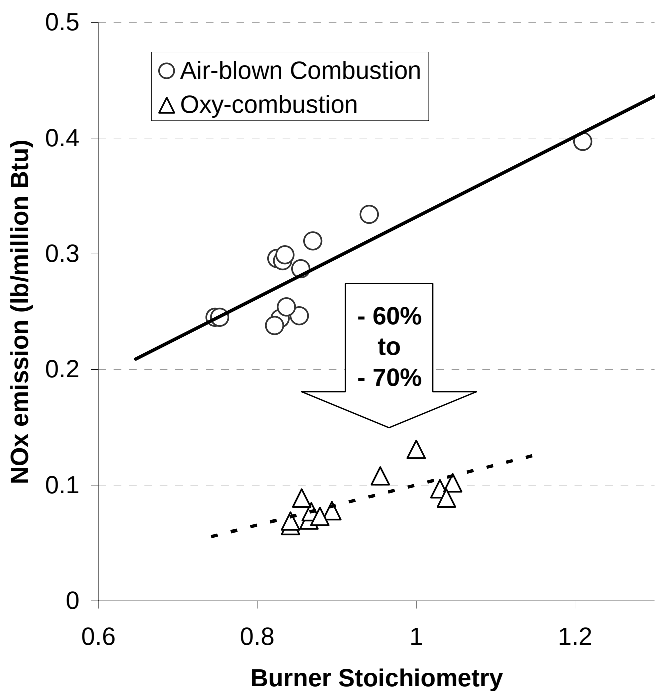

Figure 9: NO$_x$ emission versus burner stoichiometry

As shown in Figure 9, the NO$_x$ emissions were reduced by an average of 65% in the oxy-combustion versus air-blown baseline. Using B&W's DRB-4Z® low-NO$_x$ burner, the baseline NO$_x$ emission ranged from 0.24 to 0.39 lb/10^6 Btu when the burner stoichiometry was varied from 0.75 to 1.1. During the oxy-combustion tests, the NO$_x$ emission ranged from 0.065 to 0.13 lb/10^6 Btu. Such significant NO$_x$ reduction is due to the combined effect of flue gas recycle, burner stoichiometry and oxygen injection in the primary air zone. Those low NO$_x$ levels justify the assumption used in the economic study, that no SCR would be necessary for implementing the oxy-combustion process.

Flue Gas Volume and Composition

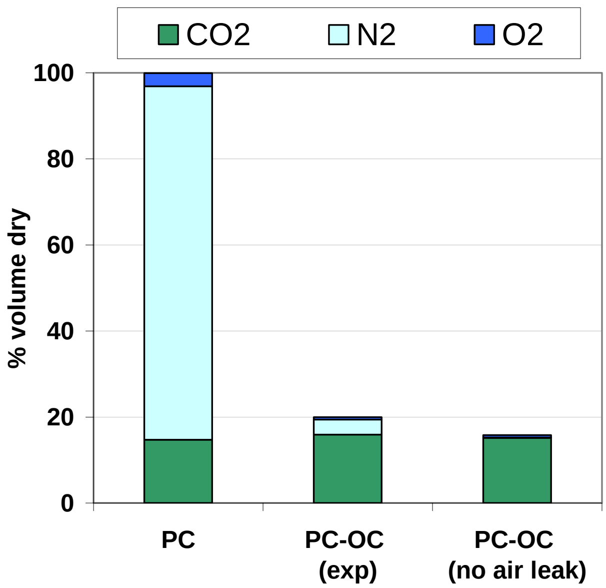

Figure 10: Flue gas volume and compositions (exp= measured during experiment, no air leak= if no air infiltration in the system)

The flue gas volume exiting the stack was 80% lower in oxy-combustion versus air-blown combustion, due to pre-combustion removal of the nitrogen. Figure 10 displays the dry flue gas composition. The dry flue gas composition measured from the PC-OC tests was around 80% CO_2 by volume, 3% O_2 and 17% N_2. Since pure oxygen was used for these tests, the N_2 content in the flue gases was attributed to air-infiltration, caused by some parts of the boiler being operated under negative pressure. In the tests, approximately 5% of the stoichiometry originates from air infiltration. If the air infiltration would be completely eliminated, the CO_2 content in the dry flue gases would reach 94 to 95%. Various means to reduce the air ingress and increase the CO_2 concentration in the flue gases are currently being investigated.

CONCLUSIONS

The PC-OC technology was shown to be a cost-effective technology for CO_2 capture from retrofitted or new PC plants. Removing the nitrogen prior to combustion offers many advantages compared to post-combustion separation from the air-fired flue gases.

Process calculations and economic analyses have been performed on PC-MEA, PC-OC and IGCC-S units of $533MW_e$ gross power output, for retrofitted and new plant configurations. Both capture technologies impact the power plant net power output, increasing the cost of electricity. The impact seemed to be much more significant for the PC-MEA process than for the PC-OC processes. The net power output was reduced by 30% with the PC-MEA system. The reduction is about 28% with the PC-OC process, 19% being due to the ASU power consumption. The cost of CO_2 avoided was around \$36/tonne for the a new PC-OC case, about \$48/tonne on a retrofit PC-OC case, and \$52 to \$64/tonne for the PC-MEA new and retrofit cases. IGCC equipped with selexol unit offers both lower cost of electricity and lower CO_2 avoidance costs. In this study, the PC plants feature a subcritical steam cycle and the costs of CO_2 avoided can be significantly lowered by considering the supercritical or ultra-supercritical steam cycles.

The PC-OC has been successfully demonstrated on a $1.5MW_{th}$ (5 million Btu/hr) pilot boiler. The tests showed similar heat transfer and flame characteristics under an optimum oxy-combustion conditions as in air-firing conditions, in spite of very significant changes in oxidizer composition from air to oxygen-enriched flue gas. This was a key result to open new opportunities for retrofit application of the technology without expensive pressure part modifications. In addition, the PC-OC technology reduces NO_x emissions by 60 to 70% below the air-blown staged baseline. No further NO_x control technology is likely to be needed. Air infiltration has been limited to 5% of the overall stoichiometry, resulting in 17% nitrogen by volume in the dry flue gases (80% CO_2). Depending on the CO_2 application (site specific), the flue gas may have to be further processed/purified. Alternative boiler upgrade and flue gas purification technologies are expected to lead to the required CO_2 purities. All processes for further purifying the flue gases will benefit from the reduced flow rate to be treated (70% lower than in air-combustion).

The performances and cost-efficiency of Oxy-Combustion technology can be further optimized, while addressing the specifics of the utility industry and ensuring the safety of the proposed solution. To meet such a challenge, AL and B&W will combine their respective expertise in oxygen production and in coal-fired boilers.

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